Beating $1/r^2$: cylindrical crucibles for large working distances

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Due to the straightforward physics of MBE (low working pressures, large mean free paths), the flux distribution of effusion sources can be calculated with high accuracy and reasonable effort using Monte Carlo algorithms [1] that are based on two assumptions: i) no interaction of the particles in the gas phase, ii) cosine law reemission from hot surfaces (crucible walls).

I use such calculations to study the deposition characteristics of long, cylindrical crucibles. The example shown in the figure shows the flux distribution (layer thickness in the substrate plane) of such a crucible as a function of its filling level, from full (top) to almost empty (bottom). The chosen geometry corresponds to a 160 mm long crucible with 14 mm inner diameter and a working distance of 240 mm at an angle of 21°.

The results show a strong variation of the flux distribution with a dramatic focusing effect for low filling levels. The best material utilization is achieved for the largest distance from the melt to the substrate, suggesting a pathway to optimize the source geometry for MBE systems with small sample sizes. Choosing a crucible with a constant cross section similar to the sample size, large working distances allow for a large number of effusion sources at a small angle to the substrate normal, leading to excellent flux uniformity. Long crucibles with a low filling level focus the material that would otherwise spread into a wide cone onto the sample, with excellent material utilization of the expensive source materials and low parasitic coverage of the chamber walls. This translates into extended campaign times.

The longer crucibles of such designs require longer heaters in the effusion sources. However, as the power dissipation of effusion sources, at least at elevated temperatures, is dominated by the radiation losses through the crucible orifice, the overall power budget of such an MBE system is not dramatically affected.

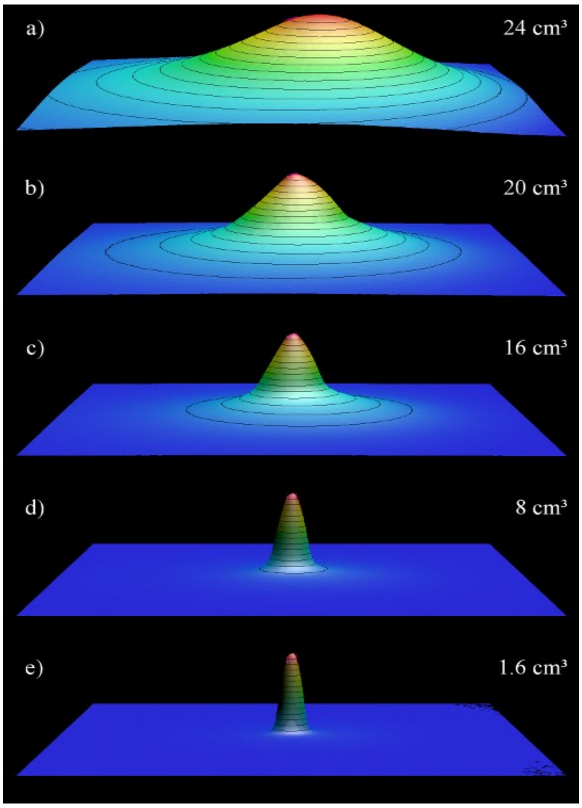

Fig. 1: Flux distributions in the sample plane as a function of crucible length vs. diameter, or filling level, for a long, cylindrical crucible

On the other hand, smaller source angles to the substrate normal allow the design of chambers with smaller outer diameter and therefore smaller footprint, in addition to their smaller volume and inner surface and therefore better vacuum with the same pumping system.

[1] Z.R. Wasilewski, G.C. Aers, A.J. SpringThorpe, C.J. Miner, J. Vac. Sci. Technol. B **9**, 120 (1991).

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